**AFRL-RI-RS-TR-2008-226**
**Final Technical Report**
**August 2008**

# FAST INTERACTIVE INTEGRATED MODELING AND STRATEGY DESIGN (FASTIMS) - THE DYNAMIC PATHWAYS AGENT-BASED MODEL

**Icosystem Corporation**



**AIR FORCE RESEARCH LABORATORY**
**INFORMATION DIRECTORATE**
**ROME RESEARCH SITE**
**ROME, NEW YORK**

# NOTICE AND SIGNATURE PAGE



AFRL-RI-RS-TR-2008-226 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

FOR THE DIRECTOR:

/s/ /s/

EDWARD L. DEPALMA
Work Unit Manager

JOSEPH CAMERA, Chief
Information & Intelligence Exploitation Division
Information Directorate

| REPORT DOCUMENTATION PAGE | *Form Approved* **OMB No. 0704-0188** |
|---|---|



| **1. REPORT DATE** *(DD-MM-YYYY)* | **2. REPORT TYPE** | **3. DATES COVERED** *(From - To)* |
|---|---|---|
| AUG 2008 | Final | Jul 07 – Feb 08 |

| | |
|---|---|
| **4. TITLE AND SUBTITLE**<br>FAST INTERACTIVE INTEGRATED MODELING AND STRATEGY DESIGN (FASTIMS) - THE DYNAMIC PATHWAYS AGENT-BASED MODEL | **5a. CONTRACT NUMBER**<br>FA8750-07-C-0099 |
| | **5b. GRANT NUMBER** |
| | **5c. PROGRAM ELEMENT NUMBER**<br>N/A |
| **6. AUTHOR(S)**<br>Denis Garagic | **5d. PROJECT NUMBER**<br>PAIN |
| | **5e. TASK NUMBER**<br>00 |
| | **5f. WORK UNIT NUMBER**<br>08 |
| **7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**<br>Icosystem Corporation<br>10 Fawcett St.<br>Cambridge MA 02138-1171 | **8. PERFORMING ORGANIZATION REPORT NUMBER** |
| **9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**<br>AFRL/RIED<br>525 Brooks Rd<br>Rome NY 13441-4505 | **10. SPONSOR/MONITOR'S ACRONYM(S)** |
| | **11. SPONSORING/MONITORING AGENCY REPORT NUMBER**<br>AFRL-RI-RS-TR-2008-226 |

**12. DISTRIBUTION AVAILABILITY STATEMENT**
*APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED. PA# WPAFB 08-4951*

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**
This report documents an Icosystem contract that was awarded under the IARPA Proactive Intelligence (PAINT) program to develop the capability to rapidly generate simulation models. This work was to address a need in the Intelligence Community to predict unanticipated consequences that emerge from complex situations. Fast Interactive Modeling and Strategy Design (FASTIMS) was the proposed integrated framework for this rapid development of simulation models. Using FASTIMS, an analyst would have been able to create a model, perform validation and calibration interactively (either alone or in a group setting), discover key indicators, quantify uncertainty, and identify data needs and design and test strategies. Due to budget constraints, this effort was terminated at an early stage so the final result was not realized. This report details the preparations for the work and the steps that were taken during the short duration of the contract.

**15. SUBJECT TERMS**
Simulation Models, Proactive Intelligence, Agent-Based Model, Network Modeling, Sensitivity Analysis

| **16. SECURITY CLASSIFICATION OF:** | | | **17. LIMITATION OF ABSTRACT** | **18. NUMBER OF PAGES** | **19a. NAME OF RESPONSIBLE PERSON**<br>Edward L. DePalma |
|---|---|---|---|---|---|
| **a. REPORT**<br>U | **b. ABSTRACT**<br>U | **c. THIS PAGE**<br>U | UU | 15 | **19b. TELEPHONE NUMBER (*Include area code*)**<br>N/A |

Table of Contents

## 1. Introduction

Fast Interactive Integrated Modeling and Strategy Design (FASTIMS) is Icosystem's integrated framework for decision support for the intelligence community. In this research, we used FASTIMS to advance the rapid assessment of technological capabilities of potential adversaries. With FASTIMS, intelligence units, analysts and decision-makers are able to create models, perform simulation validation and calibration interactively to evaluate evolving technologies of potential adversaries, discover key indicators, and quantify uncertainty. FASTIMS enables analysts to identify data needs and design and test strategies to determine performance characteristics, capabilities, and vulnerabilities of adversaries in a matter of hours or days.

This report describes Icosystem's initial efforts to develop main components for the FASTIMS framework, a generalized agent-based pathways model. Pathways processes are modeled as dynamic systems of interacting agents. Here "agent" refers broadly to bundled data and behavioral methods representing an entity constituting part of a computationally constructed world of pathways. Examples of possible agents include individuals (e.g. military, political and scientific personnel), social groupings (e.g. government agencies, research organizations/universities, firms), processes (e.g. research activities, development activities, production/employment activities), technology based entities (e.g. research programs, development programs, production programs), and physical entities (e.g. infrastructure, equipment, material resources). Thus, agents can range from active data gathering decision-makers with sophisticated learning capabilities to passive world features with no cognitive functioning. Moreover, agents can be composed of other agents, thus permitting hierarchical constructions in which the lowest level agents are characterized by continuous and discrete event-variable dynamics and the highest level agents by heuristically based decision-making mechanisms. Agent-based techniques are used to handle heterogeneity in behaviors and domain descriptions associated with Pathways Behaviors. For example, our agent-based dynamic pathways model will be capable of addressing challenging modeling issues such as modeling asymmetric information, strategic interaction, expectation formation on the basis of limited information, mutual learning, social interactions etc. The advantage of the agent-based representation is its capacity to retain all information associated with the variability and interdependency between attributes of agents which might otherwise become lost if aggregate quantities were formed directly from individual data. Another key advantage of Agent-Based modeling techniques over more standard approaches (e.g. System Dynamics techniques) is that events are driven solely by agent interactions once initial conditions have been specified. Thus, rather than focusing on equilibrium states of a system, the idea is to watch and see if some form of equilibrium develops over time. The objective is to acquire a better understanding of a system's entire phase portrait, i.e. all possible equilibriums together with corresponding basins of attraction.

## 2. Model Overview

We briefly outline the Icosystem pathways model, which is now a detailed conceptual model for which the software architecture has been implemented to the point that a simplified end-to-end model can be run. In addition, the model can import data coming from the Booz Allen Hamilton Agent-Based social network model of Leadership. The Icosystem modeling effort is inspired in part by the model described in the Bodnar text Warning Intelligence for the Information Age distributed at the PAINT kick-off meeting in September [1]. Essentially the pathways model tracks the progress of a research program through research, development, production, and finally employment.

The model contains six types of agents: Environment, Individuals (e.g. military, political and scientific personnel), social groupings (e.g. government agencies, research organizations/universities, firms), processes (e.g. research activities, development activities, production/employment activities), technology based entities (e.g. research programs, development programs, production programs), and physical entities (e.g. infrastructure, equipment, material resources).

The environment contains all other agents; it stores a socio-political, military and economic profile of a geo-political region of interest that represents actual environment in which Individuals within Social Groupings reside and perform Research, Development and Employment activities on a variety of technology based programs. These programs are designed to achieve strategic political and economic goals of the environment's governmental leadership. To execute these goals; scientific, military and political leadership jointly sets up a series of research and development programs that when executed will lead to the country's technological superiority in its geopolitical sphere of interest.

The technology based entities - programs are characterized by the following attributes: funding resources, length of the program and number of research tasks-goals that the program needs to address in order to be successful. The program agent periodically generates programs which are allocated to different Social Groupings (e.g. research institutions, universities, firms etc.) based on the level of expertise of a particular institution that are required to successfully address the program goals (e.g. if the program is allocated to a research institution which has level of expertise that is less than nominal then probability of completing the program successfully within the given time frame may be lower than for a research institute with higher rating). At this stage of modeling we are assigning the programs to different institutions randomly (note: we plan to extend the allocation methodology using market-based assignment methodologies in the future). After the program has been allocated to a social grouping or to multiple social groupings we simulate the life of the program in the research environment. That is, within the research institution there is a need for personnel with a certain level of skills necessary in order to accomplish a required set of research tasks before the program can move to its development/employment stage. The performance of individuals from the social grouping working on the program affects the speed of reaching program goals (that is, executing – completing all tasks). On the other hand, the individual performance is influenced by many factors such as individual's level of skills, available funding – financial resources needed to conduct research, physical resources and social collaboration. Our model captures the dynamics of these factors. In addition, if the required personnel are not available upon arrival of the program to a social grouping agent, the research (or development employment) institution must recruit required personnel before starting to work on the program. Also, if the personnel does not have adequate level of skills required to execute the program tasks in the projected time these personnel must be trained so that the program goals can be met (e.g. personnel on the project are Ph.D. or M.S students -they will gain the adequate level of skills while completing their educational requirements). Recruiting and Training processes can be completed domestically or abroad resulting in different level of obtained skills. Our model captures the affects of recruiting and training on the overall dynamics of program/tasks execution. The metrics indicating progress made by a social grouping during the research phase are expressed in terms of the rate of generation of conference papers, journal papers, patent applications or requests for additional funding in order to expend research activities.

The results from conference papers, journal papers and patents are used to initiate the development stage of the program life which goes through a similar cycle as in the research stage. That is, potential development programs are assigned to an institution which allocates individuals with certain skills to work on the development program. The level of skills of individuals within a social grouping, physical resources and funding are allocated to the institution affect dynamics of development program execution. The outputs of the development stage are blue prints – designs that when sent through the employment stage may result in a usable product.

The employment stage is characterized by similar dynamics as research and development stages. The employment stage is where the ultimate intention of the program becomes clear (that is, whether it was intended for civil or nefarious purposes). The model will support the estimation of the probable employment path of a program at various stages of the pathway. It will also permit exploring a variety of targetable parameters for strategy and probe design (e.g. disrupting social network between collaborators working on a program, influencing recruiting and training of individuals within social groupings, influencing delivery of equipment required to do research and development, etc…). The model will be capable of providing feedback to the other PAINT teams via a variety of metrics as well as interacting with Leadership models developed by other PAINT teams. A specific example of such feedback would be metrics associated with different types of resource requirements and utilization (e.g. requirements and use of: funding resources, equipment, personnel resources and they collaborations during research, development and employment stage.

## 3. THE GENERIC MODEL AGENTS

Generalizing from the process description above, each of the components specifying the Pathways processes will be thought as a single agent dynamically interacting with the other ones following prescribed relationships. The system agents are represented as hybrid systems that involve both continuous valued and discrete variables. In general, analyzing such complex dynamics is difficult from an analytical point of view as solutions might not exist in closed form. Because of these features, we investigate its dynamics by means of an agent-based approach. That is, within an individual agent, behavioral decisions may be done by evaluation of their dynamics described by general hybrid dynamic models (GHDS). However, the system level behavior is then determined by running dynamics describing the interactions among agents. The integration of GHDS approaches to describe the dynamics of individual agents together with agent-based simulation gives us a mean to study dynamics evolution of large scale interconnected systems in a natural way. We now take a closer look at the structure of agents and agent-based simulation of Pathways processes.

### 3.1. The Pathways Processes as a General Hybrid Agent-Based Dynamic System Automaton Model

The key component of the program agent is a new dynamic model of tracking the progress of a research program tasks through research, development, production, and finally employment. The model illustrates how the performance of individuals with certain level of skills from the social grouping working on the program affects the speed of reaching program goals (that is, executing – completing all tasks). On the other hand, the individual performance is influenced by many factors such as individual's level of skills, available funding – financial resources needed to conduct research, physical resources and social collaboration. Our model captures the dynamics of these factors.

The program tasks execution is formulated as a Generalized Hybrid Dynamical System – the system formalism for combined discrete/continuous modeling (Brocket, 1993). This formalism is a combination of two analytical approaches: 1) the discrete event automaton describing discrete phenomena corresponding to discrete states and dynamics such as the dynamics associated with a sailor's rating and pay grade transitions; and, 2) the differential equations system describing the program tasks execution which is formulated as a closed loop nonlinear control system. It is described using a set of first order coupled differential equations where causal relationships between internal and exogenous variables that influence the task execution are modeled in a form of simple linear and nonlinear feedback dependencies. In simulation, the two parts alternate in model execution. While the discrete part executes the state transition at the event times, the continuous part computes the state trajectories in between. The events define discrete changes of the continuous input values. We transform the event segments to piecewise constant segments to accomplishes this. For example, for the program agent dynamics the most frequent event transitions (e.g. workload change) occur every seven days while the continuous part describing a task progress to such an event (i.e. a piecewise constant segment) computes state trajectories for each day during a week of research, development or employment phases.

The GHDS framework provides a means to specify the system agent, using mathematical formalism defined for a hybrid automaton model (Brocket, 1993). A hybrid automaton is a system (Brocket, 1993)

$$H = (Q, \Re^n, \Sigma, \Pi, E, \Phi, \Gamma) \tag{1}$$

$Q$ is the finite set of discrete states with time based switching points indicating the time at which a particular program transition occurs assuming that all necessary requirements for such a transition are met (e.g. research stage transitions to development stage ) ), $\Re^n$ is the set of continuous states, and $\Pi$ is the finite set of discrete events. The finite set of edges, $E \subset Q \times 2^{\Re^n} \times \Pi \times \{\Re^n \to \Re^n\} \times Q$, models the discrete event dynamics of the system. An edge $E \ni e = (q_e, X_e, V_e, r_e, q_e^{'})$ is enabled when the discrete state is in $q_e$ (e.g. a 1st task of a research program allocated to a research institution) and continuous state is in $X_e$ (e.g. current level of task's progress). When the transition is taken, the event $V_e \in \Pi$ is accepted, the continuous state is reset according to map $r_e$. This mapping can simply restart the continuous state from a new set of initial conditions (e.g. the last values of such states at the final time while in $q_e$ stat). Then the system enters discrete state $q_e^{'}$ (e.g. 2nd task of the research program allocated to the same research institution). In this representation of discrete event automaton we account not only for the order in which events occur but also for event occurrence times which leads us to a timed discrete event system model. In addition, at any given time state ***q***, the occurrence of an event at a given state can lead to several possible next states. In our model we can select one of these next states according to some perspective set of rules. We also employ a discrete event controller to model a situation in which personnel can be abruptly "redirected" in their process of skill set build up due to new strategy initiatives. A discrete event controller for DES is an external discrete event control that disables some events and enables the others.

By modeling a program's transition dynamics as a discrete event system, an optimal probing and strategy trajectory (e.g. disrupting social network between collaborators working on a program, influencing recruiting and training of individuals within social groupings, influencing delivery of equipment required to do research and development, etc…) can be derived. Finally, $\mathbf{\Sigma} = \{\Sigma_q\}_{q \in Q}$ is the collection of constituent dynamical systems where each $\Sigma_q = \lfloor X_q, \Gamma_q, U_q, \Phi_q \rfloor$ is a closed loop dynamical system with inputs describing a task's progress corresponding to a particular discrete state ***q***. Here, the $X_q \subset \Re^n$ are the continuous state spaces and $\Phi_q$ are called the continuous dynamics, $\Gamma_q$ transition system. Continuous- and discrete-time transition systems denote the cases where $\Gamma_q = \Re$ (or $\Re_+$) and $\Gamma_q = Z$ (or $\mathbf{Z}_+$) respectively[1]. $U_q \subset \Re^m$ is the set of piecewise constant inputs $u \in U_q(t, X_q(t))$ (e.g. control input determines how quickly a task's goal can be reached with available personnel assigned to work on the task). The continuous state evolves according to the closed loop differential inclusion $\dot{X}_q(t) \in F_q(\mathbf{q}(t), X_q(t), U_q(t, X_q(t)))$.

In simulation, the two parts alternate in model execution. While the discrete part executes the state transition at the event times, the continuous part computes the state trajectories in between. The events define discrete changes of the continuous input values. We transform the event segments to piecewise constant segments to accomplish this.

[1] The symbols **R**, **R+**, **Z**, and **Z+** denote the reals, nonnegative reals, integers, and nonnegative integers, respectively.

### 3.2 Analysis of the Model: Stability Analysis

The GHDS framework, Equation (1), postulates certain basic behavioral actions on the part of the actors. What is important in this description is that a particular task's overall performance during the research, development of employment stages become significantly altered if the strength of any one of these factors becomes great enough (exceeds the critical threshold). In this case, the system may become unstable to the "stimulus" being imposed, for example, the critically undermanned program increases the expected work per personnel assigned to the program which eventually results in performance degradation. It is therefore, important to know the range of values for which the task dynamic model is stable, and from the point of view of the decision maker, it is important to know the range of values of the parameters at which the system is most sensitive to change, so that a timely policy initiative may be made to effect a desired change and also to be aware when an unwanted change may be likely to occur. In other words, for which values of the parameters of the system should the decision maker be alerted to a likely significant change of system performance and in what direction is this change going to occur? Also, what "perturbation" must be imposed upon the system to affect its performance in a desired way? The proposed mathematical formalism for modeling Pathways processes allows us to address the above mentioned issues by applying mathematical stability analysis for such a hybrid interconnected time-varying dynamics system (Garagic et al., 2006).

## 4. Model Parameters and Data Requirements

As with any modeling approach, model calibration against real-world data is a key challenge. In order to make this process more efficient, we have provided a list of ideal data requirements. These parameters are of different nature: some of them are currently implemented in the model and their possible ranges were determined in consultation with experts. Others, however, are kept variable due to scarce knowledge about their real-world value or usage.

Inputs from a Leadership Model:

- network topology of scientific, military and political social networks (nodes/vertices = scientists, politicians, military personnel; edges = nodes' domestic and foreign connections)
- number of connections among a person's friends – a measure of cliquishness of a group.
- strength of connections
- associations of nodes to a social network with research/development/production/political/military institutions (i.e. person A works in University of Teheran)
- capabilities - level of skills of individuals (nodes/vertices)
- number of publications: conference papers, journal papers and patents (for a given node)

Information about the Program(s) personnel or teams (from scientific/political/military social networks) is currently working on. Attributes of the program would include:

- funding
- duration
- collaborative requirements
- type of research
- funding agency -- grantors
- personnel requirements (e.g. skill set of personnel)
- is the program classified or unclassified

Information about Research Institutions:

- research institution is involved in (types of research)
- personnel (number of grad students, professors, etc.)
- rating (e.g. how capable is the institution in conducting research with respect to a specific field)
  - amount of funding received for research activities
  - laboratory capabilities -- equipment
- total number of publications per year
- international/domestic collaboration activities
- how many grad students are studying abroad (e.g. USA, Europe)
- how many grad students graduate per year
- how many exchange students
- average duration of Ph.D. and M.S. programs

Information about Development Institutions:

- characteristics of national labs. (names, location, capabilities to carry on research)
- equipment - or information about expensive equipment, purchasing dates etc.
- amount of funding received / available
- collaboration activities (international and domestic)
- type of personnel associated with development institute-national lab. and their skills
- number of publications coming from the development institute - national lab.
- sponsorship of new research activities (will give us an indication if the development was stacked on something)

Information about Production facilities:

- possible production facilities
  locations
  type of facility
  rating - modernization level
  collaborations among facilities
- privately/government owned (subcontracting relationship)
- raw materials used/on site
- equipment on site

- personnel (number of workers)
- exporting capabilities
- rate of production/quantities

## 5. Model Metrics

Our Fast Interactive Integrated Modeling and Strategy Design framework is capable of generating an extensive list of important metrics for the intelligence community. Some of these metrics include performance against historical data, usability, confidence, timeliness, and rapid identification of information needs. An extensive list of metrics is as follows:

**Quality—measures of Accuracy**
-Comparison with "expert" solution;
-Percent agreement between system and analyst;
-Amount of evidence used in analysis
-Number of target criteria items (e.g. Target criteria items, as described in the text, include variables, hypotheses, documents found, etc. that experts identify as relevant and important data that should be produced—i.e., success criteria.) considered by system
-Number of target criteria items missed by system

**Confidence**
- Analyst confidence in findings

**Presentation quality and clarity**
- Accessibility: The extent to which information is available, or easily and quickly retrievable
- Concise representation: The extent to which information is compactly represented
- Consistent representation: The extent to which information is presented in the same format
- Ease of manipulation: The extent to which information is easy to manipulate and apply to different tasks
-Interpretability: The extent to which information is in appropriate languages, symbols, and units,
and the definitions are clear

**Coverage and reliability:**
-Appropriate amount of information: The extent to which the volume of information is appropriate for the task at hand
-Believability: The extent to which information is regarded as true and credible
-Completeness: The extent to which information is not missing and is of sufficient breadth and depth for the task at hand
-Free-of-error: The extent to which information is correct and reliable
- Objectivity: The extent to which information is unbiased, unprejudiced, and impartial

**Usability and analysis quality**

-Relevancy: The extent to which information is applicable and helpful for the task at hand

-Reputation: The extent to which information is highly regarded in terms of its source or content

-Timeliness: The extent to which information is sufficiently up-to-date for the task at hand

-Value-Added: The extent to which information is beneficial and provides advantages from its use

The formulas used to calculate some of the above stated metrics are:

Accuracy = Number of correctly answered parts / Total number of parts

Precision = Number of relevant results identified by the subject / Number of all results identified by the subject

Recall = Number of relevant results identified by the subject / Number of relevant results identified by the expert

## 6. Model Calibration, Probes and Strategy Design

Fast Interactive Integrated Modeling and Strategy Design (FASTIMS) combines several leading-edge technologies developed by Icosystem Corporation into an innovative, integrated framework for intelligence analysis: In addition to ABM and Network Model described above, this framework also includes automated interactive calibration, sensitivity analysis, surrogate variable discovery, and design of scenarios (“what-if”) and intervention strategies. We’ll briefly focus on our novel approach to calibration, Interactive Evolutionary Calibration, or IEC.

Even when quality data is available, it is often the case that only an expert will be able to tell whether a model makes sense or not, or tell apart two models that fit the data equally well. IEC works by creating a range of alternative models, asking the user for feedback, and re-creating a set of models for the user to examine, and so forth, until the user is satisfied with the model. Throughout this process, IEC always attempts to maximize the model’s fit to whatever quantitative data is available. FASTIMS works with one user or multiple users. With IEC in particular, it is a natural extension of the FASTIMS platform to involve a range of analysts, domain experts and points of view in building and calibrating a model in a collaborative manner.

Thus far we have explored three areas surrounding the interactive evolution and calibration of models:

**The implications of uncertainty in data and probes for our modeling Efforts**

Specifically, it evident that we will never have crisp enough data to permit the determination of a single best model for whatever entity, like the Iranian government, is under consideration. This observation highlights the critical role played by our interactive evolutionary/calibration (IEC) component. IEC will enable an analyst to explore a space of possible models which are all consistent with the current data such that they can use their own judgment and intuition to guide the selection of a small number of relevant models.

**The use of probe and strategy modeling in IEC**

Besides judging models on the basis of their dynamics, we allow analysts to apply probes and strategies to a space of models. It is possible that analysts have intuitions about the types of strategies and probes to which an entity like Iran will respond; they probably also have expectations about how that response should look. By permitting analysts to apply probes and strategies during the IEC step, we can leverage these intuitions and expectations towards producing better models.

**The pitfalls of optimizing or calibrating for robustness**

If the real-world is about to reach a tipping point, but we optimize or calibrate models to be robust with respect to parameter changes, then our model might “smooth out" a real-world transition. Thus we should be cautious about using robustness as a criterion for selecting models. Steven Bankes of Evolving Logic, who is working with the Lockheed Martin group, has proposed a technique which potentially mitigates this smoothing out effect. Bankes' “Exploratory Modeling" integrates the behavior of many different models into a broader picture of a system. If we include models which are not necessarily robust into an exploratory modeling framework, particularly during IEC, then perhaps we can mitigate this potential problem of “calibrating away" a real-world tipping point.

## 7 Simulation Results and Future Research

The simulation scenario results demonstrating capabilities of our integrated leadership and pathways model and strategy design techniques are described in the attached .pdf file, Appendix 1. The Agent-Based model is capable of testing different hypothesis regarding the nanotechnology product intended use as well as validating variety of strategies designed in order to influence the course of development of nanotechnology based products.

We plan to use these capabilities of the ABM of Leadership and Pathways to generate searchable space of strategies for proactive intelligence. In order to discover the most effective strategies within the searchable exploration space, we plan to apply optimization techniques based on evolutionary computing in our future research. Details of this approach will be outlined in an upcoming White Paper which we are preparing for Dr. Peter Brooks per his request.

## 8. References:

Barabasi, A.-L., Bonabeau, E. (2003) Networks: the architecture of complexity, Scientific American May 2003, 60-69.

Bodnar, J.,W., *Warning Analysis for The Information Age: Rethinking the Intelligence Process*, Joint Military Intelligence College, December 2003.

Bonabeau, E. (2002) Agent-based modeling: methods and techniques for simulating human systems, Proc. Nat. Acad. Sci. USA 99, 7280-7287.

Garagic,D.,Trifonov,I.,and Gaudiano,P., (2007), *Agent Based Modeling as a Tool for Manpower and Personnel Management*, In Proceedings of the 2007 *International Conference of the System Dynamics Society 2007, July 2007, Boston MA.*

See Also: 07-C-0099 Demo Presentation, .pdf file